GAMMA-GAMMA ANGULAR CORRELATION IN THE DECAY OF COBALT-60

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BURTON J. CONWAY

CAPTAIN, UNITED STATES ARMY

Submitted in partial fulfillment of

the requirements for the degree of

MASTER OF SCIENCE

IN

PHYSICS

UNITED STATES NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

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ABSTRACT

This is a continuation of the work of assembling and testing the equipment necessary to conduct gamma-gamma angular correlation experiments, started by Fort A. Verser, Jr. at the US Naval Postgraduate School (1).

No substantial changes were made in the equipment, but rather a rerun of the Cobalt-60 experiment was made to confirm the results obtained in the previous work. A comparison of the previous work confirms that there is a definite distortion in the shape of the observed correlation function.

The statistical analysis of the data and the solid angle corrections required for evaluation of the results have been programmed for calculation by use of the 1604 Digital Computer. This paper outlines these programs in detail.

The author wishes to express his appreciation for the assistance given him by Professor Harry E. Handler and for his guidance throughout this investigation. Appreciation is expressed to Professor Edmund A. Milne for his advice and comments. Captain T. R. Abernathy, USMC, was very helpful in providing valuable assistance and discussions on various aspects of the computer programing. The cooperation and assistance of Mr. Mervyn C. Brillhart in maintaining and testing the electronic equipment was indispensable.

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CHAPTER I

INTRODUCTION

The decay of Cobalt-60 to an excited state of Nickel-60 and the angular correlation of the resulting gamma-gamma cascade have been studied extensively experimentally (2,6,8,9, and others) and the results of the correlation measurements agree very well with the theoretical correlation for the decay scheme shown in Figure 1. Consequently, the decay of Cobalt-60 is now used as one standard for the testing of correlation equipment.

Angular correlation equipment was assembled at the US Naval Postgraduate School by Verser in 1960 for the investigation of the properties of low-lying excited nuclear states. His testing of the operating characteristics of the equipment by the angular correlation of the cascading gamma rays resulting from the decay of Cobalt-60 yielded an observed correlation curve whose shape was not in agreement with the theoretical curve. This work was initiated in order to attempt to verify Verser's results.

In order to facilitate the statistical analysis of the data, a program has been worked out for the use of the 1604 Digital Computer. The program follows the procedures outlined by M.E. Rose (2) and is contained completely in Appendix 1.

An additional program has been written to compute the solid angle corrections, which must be applied to the theoretical curve, by the method of M.E. Rose (2). This progam is outlined in Appendix II.

The results of this work agreed within statistical expectation with those obtained by Verser, indicating that the unexpected shape of the curve is apparently real and not an instrumental effect. These results are given in Chapter VI.

PARTIAL DECAY SCHEME OF COBALT-60

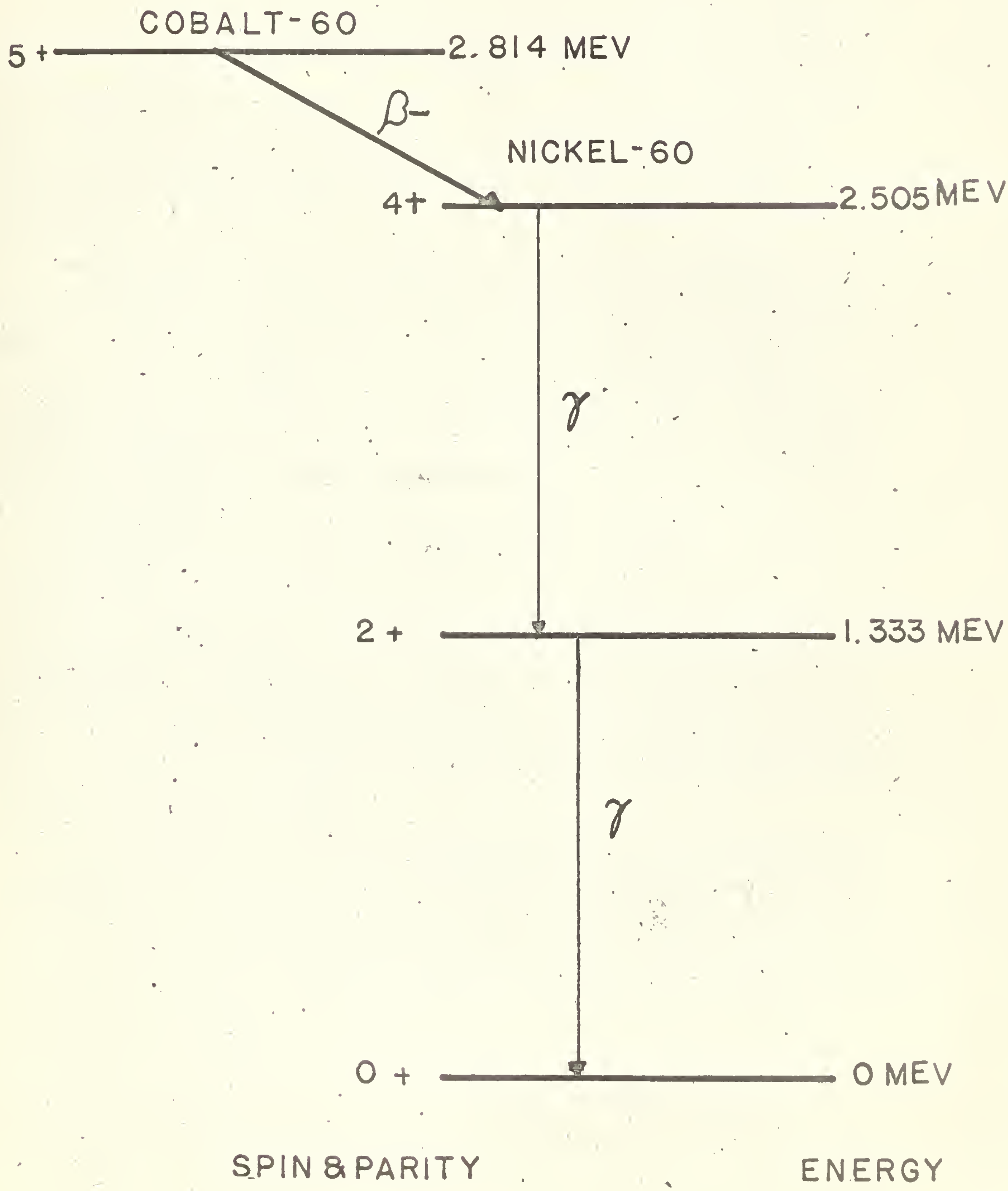


FIGURE I

CHAPTER II

THEORETICAL CONSIDERATIONS

The determination of the angular momentum quantum numbers, or spins, of low-lying short-lived excited nuclear states by the nuclear spectroscopic tool, known as angular correlation of successively emitted radiations, is quite common practice today. Only within recent years, because of the vast advancement of electronics, has practical utilization of this tool become possible.

Since nuclei, under ordinary conditions, are randomly oriented in space, it is not possible to observe a radiation pattern. This is due to the fact that the probability of emission of a radiation by an excited nucleus, depends on the angle between the nuclear spin axis and the direction of the emission. Therefore, in order to observe a radiation pattern, it is first necessary to orient the nuclei.

One method of orienting certain nuclei consists of placing the sample in an electric field gradient or a strong magnetic field at a very low temperature. Another method, the one used in the present consideration, consists of selecting nuclei whose nuclear states have spins lying in preferred directions. This happens to be the case for the intermediate state if a nucleus decays by successive emission of two radiations.

In an angular correlation experiment the first radiation is observed in a fixed direction. This establishes an axis to which the direction of emission of the second radiation, originating from the state formed by the first, can be referred. The second radiation has preferred angles of emission with respect to the direction of the first.

In order that the correlation exhibit maximum anisotropy, the angular momentum vector of the intermediate state must not change

direction significantly before the second radiation occurs. The mean life of the intermediate state must be less than about 10^{-8} seconds, the typical precession period of the nuclear spin about local perturbing fields. The angular correlation function is determined by the nature of the radiations and by the spins of the states involved, and thus its measurement may lead to an unambiguous choice of spins for the states.

The theoretical expressions for the correlation functions have been worked out for a large number of cases of interest (7). For the particular case of a gamma-gamma cascade, the correlation function $W(\theta)$ is

$$W(\theta) = \sum_{n=0}^{n_{max}} A_n P_n(\text{Cos } \theta) = \sum_{n=0}^{n_{max}} B_n \text{Cos}^n \theta \tag{1}$$

where P_n is the Legendre Polynomial of even order n, n_{max} is the smallest even integer of the set of three numbers consisting of twice the multipole order of each of the two gamma rays, and θ is the angle between the directions of emission of the two gamma rays.

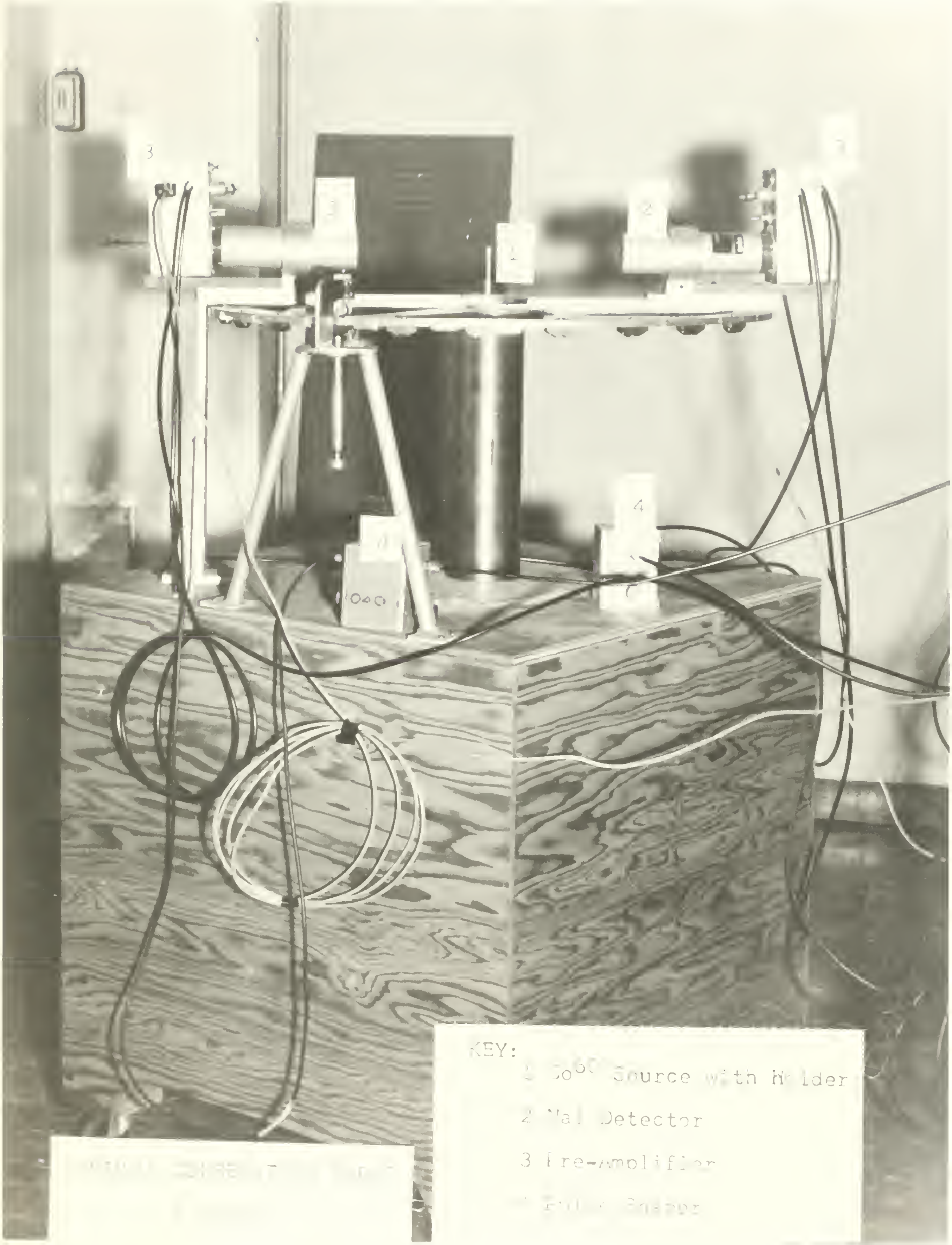
The theoretical correlation function for the cascade in Nickel-60, assuming point detectors and a point source, is

$$W(\theta) = 1 + 0.1020\, P_2(\text{Cos } \theta) + 0.0091\, P_4(\text{Cos } \theta) \tag{2}$$

with an anisotropy

$$R = \frac{W(180^\circ) - W(90^\circ)}{W(90^\circ)} = 0.1667 \tag{3}$$

Many workers, after correcting these theoretical results for the effect of non-point detectors have found good agreement between them and their experimental correlation results.


KEY:
1 Co60 Source with Holder
2 NaI Detector
3 Pre-Amplifier
4
1
2
3
4

CHAPTER III

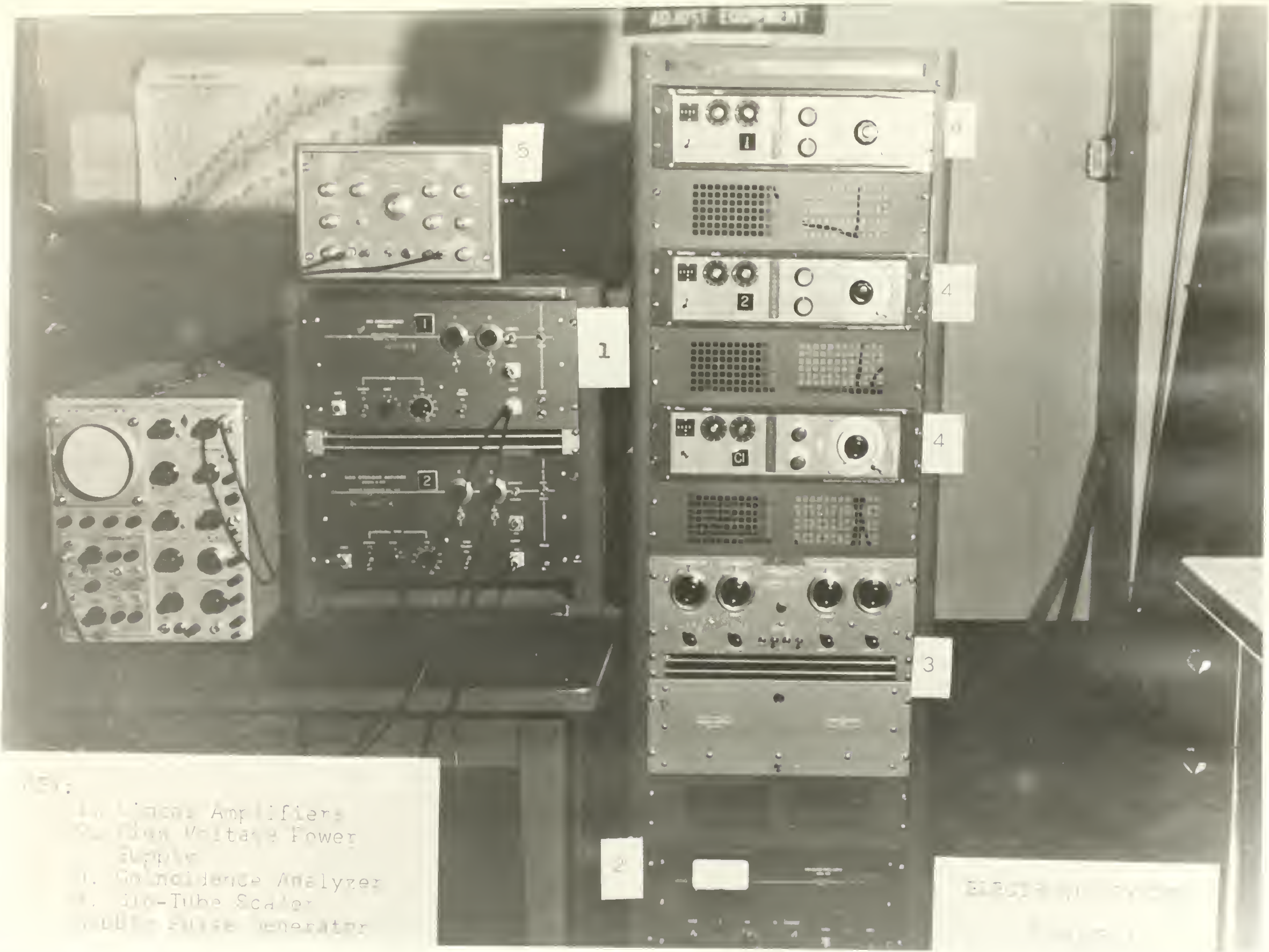
DESCRIPTION OF EQUIPMENT

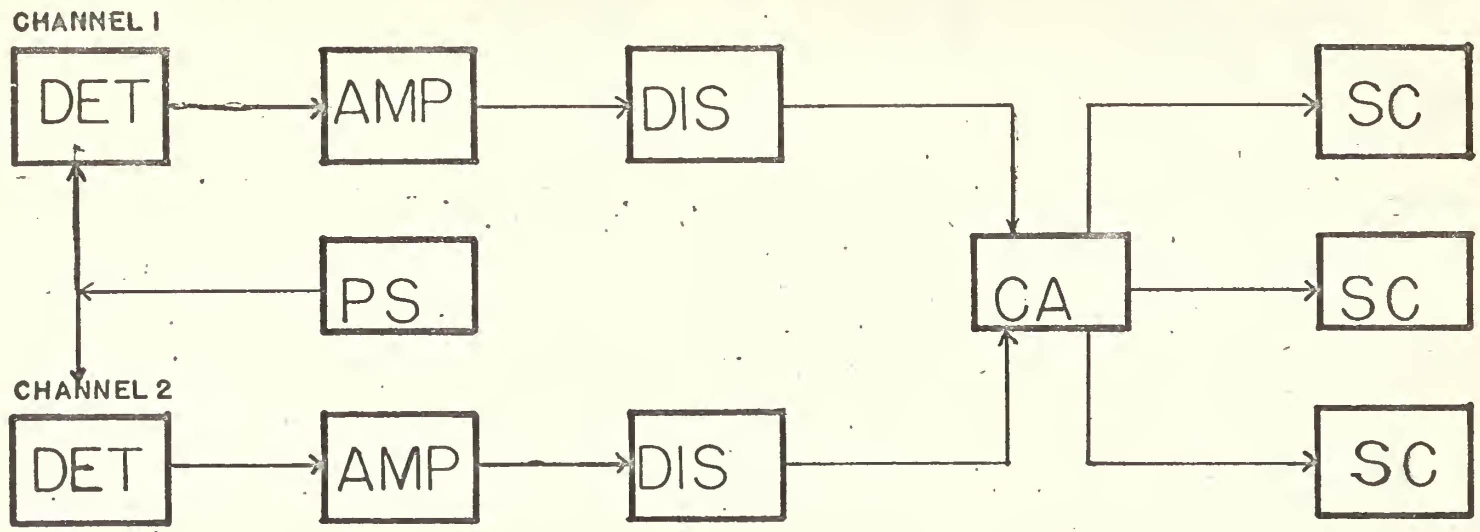
The equipment needed for the gamma-gamma correlation measurements must furnish means for detecting the radiation, pulse-height amplification with selection or discrimination, coincidence analysis, and adequate recording of the counts in the various counting channels. A mechanical system must also be provided for mounting the detectors and changing their relative positions and for holding and positioning the radioactive source.

The apparatus used for this work was that assembled by Verser and described in detail in his report. Therefore, only a brief description of the equipment and of the minor alterations performed on it will be presented.

Figure 2 is a photograph of the mechanical setup. The original base of the correlation table has been replaced, the new base is of solid brass with a bearing mounted shaft to enable accurate manual detector positioning.

The electronic equipment (Figure 3) has the functions of detection of the radiation, pulse-height amplification and discrimination, coincidence analysis, and recording the number of counts. The only change in the electronic equipment was in the pulse-shaping networks used in the initial calibration of the apparatus. The pulse shapers were rebuilt to give a better simulation between the test pulses and the actual pulses encountered under operating conditions.


1
2
3
4
4
5
Amplifiers
Voltage Power
Supply
Coincidence Analyzer
-Tube Scaler
Generator



KEY: DET - DETECTOR
AMP - LINEAR AMPLIFIER
DIS - DIFFERENTIAL DISCRIMINATOR
SC - GLO-TUBE SCALER
PS - HIGH VOLTAGE POWER SUPPLY
CA - COINCIDENCE ANALYZER

SCHEMATIC DIAGRAM OF THE ELECTRONIC SYSTEM

FIGURE 4

CHAPTER IV

EXPERIMENTAL ANALYSIS

The angular correlation function $W(\theta)$ (Equation 1) must be expressed in terms of experimentally-observable quantities. The equipment records the total number of coincidences as a function of the angle between the detectors, and the total number of radiations captured in each channel. C_t, the total number of coincidences in a counting period, is given by

$$C_t = C_g + C_a + C_b \tag{4}$$

where

C_g = the number of genuine coincidences due to the two cascading radiations,

C_a = the number of accidental coincidences due to the finite resolving time of the electronic equipment, and

C_b = the number of background coincidences.

The half-life of the source is long compared to the time required to collect the necessary data; therefore, equation (4) can be rearranged and rewritten in terms of counting rates:

$$\dot{C}_g = \dot{C}_t - \dot{C}_a - \dot{C}_b \tag{5}$$

$\dot{C}_g$ can also be expressed in terms of other parameters:

$$\dot{C}_g = (\varepsilon_{11}\alpha_{11}\rho_{11}\,\alpha_{22}\rho_{22} + \varepsilon_{12}\alpha_{12}\rho_{12}\varepsilon_{21}\alpha_{21}\rho_{21})\Omega_1\Omega_2\emptyset_{12}N_0\bar{W}(\theta_i) \tag{6}$$

where

$\dot{N}_o$ = the absolute source strength

$\emptyset_{jk}$ = the fraction of nuclei decaying by the emission of gamma ray "j" and gamma ray "k" in a cascade

Ω_i = the fractional solid angle subtended by the crystal in Channel "i"

ρ_{ij} = the fraction of gamma rays "j" which leave the source in the right direction to enter crystal "i" that are not absorbed before reaching the crystal

ε_{ij} = the total efficiency of the crystal in Channel "i" for gamma ray "j"

α_{ij} = the fraction of the number of gamma rays "j" captured by the crystal in Channel "i" whose pulse heights are accepted by the energy discrimination of Channel "i"

$\bar{W}(\theta_m)$ = the angular correlation function at an angle θ_m averaged over the solid angles used.

$\dot{N}_i$, the counting rate in Channel "i", can also be expressed as a function of certain of these same parameters.

$$\dot{N}_i = \Omega_i \; \phi_i \dot{N}_o \sum_j \varepsilon_{ij} \alpha_{ij} \; \rho_{ij} + \dot{N}_{ib} \tag{7}$$

where

ϕ_i = the number of gamma rays "i" per disintegration

$\dot{N}_{ib}$ = the background counting rate in channel "i"

From Equations (5) and (6) we get for the correlation function,

$$\bar{W}(\theta_m) = \left\{ \frac{\dot{C}_g}{f\dot{N}_o} \right\}_m = \left\{ \frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{f\dot{N}_o} \right\}_m \tag{8}$$

where f is the appropriate function of the ε's, α's, ρ's, and ϕ's.

By combining Equations (7) and (8), we get for the correlation function

$$\overline{W}(\theta_m) = \left\{ \frac{(\dot{C}_t - \dot{C}_a - \dot{C}_b)\ \mathring{N}_o g}{(\dot{N}_1 - \dot{N}_{1b})\ (\dot{N}_2 - \dot{N}_{2b})} \right\}_m \qquad (9)$$

where g is a function of the ε's, α's, ρ's, Ω's $\emptyset$'s.

In this form $W(\theta_m)$ is relatively insensitive to equipment stability. Therefore, it is only necessary to calculate the modified correlation function given by

$$\overline{W}'(\theta_m) = \frac{\overline{W}(\theta_m)}{g \mathring{N}_o} = \left\{ \frac{(\dot{C}_t - \dot{C}_a - \dot{C}_b)}{(\dot{N}_1 - \dot{N}_{1b})\ (\dot{N}_2 - \dot{N}_{2b})} \right\}_m \qquad (10)$$

The correlation runs were done with the movable detector at seven angles: 90°, 105°, 120°, 135°, 150°, 165°, and 180°. A minimum of six two-hour counting periods were completed at each angle, and the angular order in which they were taken was varied to minimize any systematic fluctuations. Each run yielded single channel counting rates of approximately 1200 counts per second and a total coincidence rate of approximately 1.1 counts per second.

Before the experimental results can be compared to theory, the data must be checked and corrected, if necessary, for the various deviations from the ideal arrangement, i.e., centered point source, no spurious coincidences due to the coincidence resolving time, no scattering, no background, and perfect stability of the electronic equipment. In addition, the theoretical correlation function must be corrected for non-zero solid angle detectors. The methods for accounting for these effects are discussed in the following paragraphs.

A. SOURCE SIZE AND POSITIONING

As a test of the positioning of the source in the center of the correlation table, the integral counting rate of a portion of the Cobalt-60 spectrum was measured in each channel as a function of the angle between the counters. This was done by Verser and checked again after the base of the correlation table had been changed. Within statistical expectations, the counting rates were constant. The source has a volume of about 0.001 cubic inches and can be regarded as a point source at the distance at which the detectors were placed from it.

B. SCATTERING

Compton scattering occurring outside the detectors can give rise to unwanted coincidences. These in general will tend to smear out the measured correlation function. This problem is minimized by use of scintillation crystals as detectors and accepting only the full-energy peaks of the desired gamma rays. The method for determining the pulse height selection limits has been discussed in detail by Verser.

C. BACKGROUND CORRECTION

With the discriminators at the same settings as were used during the correlation runs, background runs were made before and after the correlation runs. The background coincidence counting rate was negligibly small and the background rate of each channel was such as to yield total background counts of the order of 0.4 percent of the total counts in each channel during the correlation runs. These background rates were used as corrections to the gross counting rates obtained during correlation runs.

D. DETERMINATION OF GENUINE COINCIDENCE RATE

Since the background coincidence counting rate proved experimentally

to be negligible, Equation (5) becomes

$$\dot{C}_g = \dot{C}_t - \dot{C}_a$$

For the total counting time, T, the total number of coincidences is $\dot{C}_t T$ and the standard deviation in the total coincidence rate is

$$\sigma_t = \sqrt{\frac{\dot{C}_t}{T}} \qquad (11)$$

Therefore, the standard deviation of the genuine coincidence rate is

$$\sigma_g^2 = \sigma_t^2 + \sigma_a^2 = \frac{\dot{C}_t}{T} + \frac{\dot{C}_a}{T} \qquad (12)$$

The accidental coincidence rate is given by

$$\dot{C}_a = 2\tau_r \dot{N}_1 \dot{N}_2 \sim 2\tau_r \dot{N}_o^2 \qquad (13)$$

where

τ_r = Coincidence resolving time of the coincidence analyzer.

In order to minimize the accidental coincidence rate, the source strength must be kept as small as possible. However, if the source strength is decreased, the counting time must be increased to obtain a specified precision in the counting rate. Thus, a compromise must be reached between precision and counting time.

The smallest resolving time obtainable with the present equipment is experimentally determined to be

τ_r = (0.1820 $\pm$ 0.0016) microseconds;

this resulted in an accidental coincidence rate that was about 30% of the

total coincidence rate. The approximate source strength of the water solution of $CoCl_2$ used in this experiment was 0.05 millicuries of Cobalt-60.

E. REFERENCE COUNTING RATE

With the discriminator in each channel adjusted to accept only the full-energy peaks of the desired gamma rays, the integral counting rate of the Cobalt-60 spectrum in each channel was determined. This gave a reference counting rate for each channel. During the course of the correlation runs, either the discriminator settings or the gains of the linear amplifiers were adjusted before each run so that, the integral counting rate agreed within $\pm$ 5 cps with these reference rates (Table 1).

TABLE 1

REFERENCE COUNTING RATES

$$\dot{N}_1 = (1085.26 \pm 0.57) \text{ cps}$$

$$\dot{N}_2 = (1117.32 \pm 0.59) \text{ cps}$$

As a measure of the gain fluctuations during each counting run, the integral counting rate of each channel was measured after the run using the same discriminator setting that was employed during the run. The difference between this counting rate and the reference counting for that channel was determined. If the variation exceeded $\pm$ 20 cps in either channel, the run was discarded.

This procedure resulted in about 30% of the runs being discarded because they fell outside of the maximum acceptable fluctuation. This indicates that the electronic system is not as stable as it should be. A check of the line voltage revealed substantial fluctuations during any 24-hour period. The temperature of the room was not controlled in any manner and varied considerably. These could have been the major causes of the large counting rate fluctuations since the discriminators are highly sensitive to both temperature and voltage variations.

F. SOLID ANGLE CORRECTIONS

The solid angle correction which must be applied to the theoretical correlation function to account for the non-zero solid angle of the detectors and enable a comparison to be made with the measured function is described by Rose (2). The correction for two cylindrical crystals whose axes intersect at the source involves the numerical evaluation of integrals of the form

$$I_{n,i} = \int_o^{\gamma_i} P_n \left(\mathrm{Cos}\ \emptyset\right) \left\{1 - e^{-\tau_i X_i(\emptyset)}\right\} \mathrm{Sin}\ \emptyset d\emptyset \qquad (14)$$

where

τ_i = the full-energy absorption coefficient of the detector in Channel "i" for the gamma ray;

γ_i = the half-angle subtended by the front face of the crystal in Channel "i";

$$X_i(\emptyset) = t_i \mathrm{Sec}\emptyset \quad \text{for } 0 \leq \emptyset \leq \mathrm{Tan}^{-1} \frac{-r_i}{h_i + t_i} ;$$

$$X_i(\emptyset) = r_i \mathrm{Csc}\emptyset - h_i \mathrm{Sec}\emptyset \quad \text{for } \mathrm{Tan}^{-1} \frac{r_i}{h_i + t_i} \leq \emptyset \leq \gamma_i ;$$

where

h_i = the distance from the source to the crystal in Channel "i";

t_i = the thickness of the crystal in Channel "i",

r_i = the radius of the crystal in Channel "i".

The attenuation factors, Q_n, are functions of these integrals:

$$Q_n = \left[\frac{I_{n,1}}{I_{o,1}}\right] \left[\frac{I_{n,2}}{I_{o,2}}\right] \qquad (15)$$

The corrected correlation function becomes

$$\overline{W}(\Theta) = \sum_{n=o}^{N_{max}} Q_n A_n P_n(\mathrm{Cos}\Theta)$$

CHAPTER V

EXPERIMENTAL RESULTS

The modified correlation function for the k^{th} run at angle θ_m given by Equation (10) is

$$\bar{W}'_k(\theta_m) = \left\{ \frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{(\dot{N}_1 - \dot{N}_{1b})\ (\dot{N}_2 - \dot{N}_{2b})} \right\}_k$$

This means that the seven counting rates $\dot{C}_t$, $\dot{C}_a$, $\dot{C}_b$, $\dot{N}_1$, $\dot{N}_{1b}$, $\dot{N}_2$, and $\dot{N}_{2b}$ must be determined for each run at each angle and the standard deviation of each rate calculated.

The background counting rates $\dot{N}_{1b}$ and $\dot{N}_{2b}$ for each run were experimentally determined. The single-channel counting rates corrected for scaling losses yielded $\dot{N}_1$ and $\dot{N}_2$. The accidental counting rates were calculated for each run from Equation (13). The total coincidence counting rate, $\dot{C}_t$, was experimentally determined. The background coincidence rate, $\dot{C}_b$, was negligible throughout the experiment.

The experimental value of the modified correlation function $\bar{W}'_k(\theta_m)$ and its standard deviation were calculated for each run at each angle. From these the weighted mean $\bar{W}'(\theta_m)$ and its standard deviation were computed for each angle.

The weighted mean of the measurements taken at each angle was determined by using the inverse square of the standard deviation of each measurement as a weighting factor:

$$\bar{W}'(\theta_m) = \frac{\displaystyle\sum_{1}^{N_m} \frac{\bar{W}'_K(\theta_m)}{\sigma_K^2}}{\displaystyle\sum_{1}^{N_m} \frac{1}{\sigma_K^2}} \qquad (18)$$

where

N_m = number of runs at the angle θ_m.

The standard deviation of the weighted mean ($\bar{W}'$) was calculated from the individual standard deviations:

$$\frac{1}{\sigma^2(\bar{W}')} = \sum_{1}^{N_m} \frac{1}{\sigma_K^2} \qquad (19)$$

A comparison between the standard deviations of the means calculated from Equation (19) and those calculated from

$$\sigma^2(\bar{W}') = \sum_{1}^{N_m} \frac{\left[\bar{W}'(\theta_m) - \bar{W}(\theta)\right]^2}{N_m(N_m - 1)} \qquad (20)$$

revealed no significant differences. Therefore the standard deviation obtained from Equation (19) were used in subsequent calculations and the method discussed in paragraph E Chapter IV for treating gain instabilities is realistic.

The values of the weighted means and their standard deviations are tabulated in Table 2.

TABLE 2

The Weighted Means $\bar{W}'(\theta_m)$

θ_m (degrees)	Weighted Mean	Standard Deviation
90	5046	45
105	4925	33
120	5109	21
135	5211	36
150	5556	35
165	5667	24
180	5907	43

A curve of the form $\bar{W}'(\theta) = \sum A'_n P_n(\cos\theta)$ was fitted to the experimental $\bar{W}'(\theta_m)$ by the method of least squares as outlined by Rose (2). This analysis was programmed to be carried out by the 1604 computer. (See Appendix II for details).

The values of A'_n are given by the matrix equation

$$\|A'\| = \|A^T\omega A\|^{-1} \cdot \|A^T\| \cdot \|\omega\| \cdot \|\mu\| \tag{21}$$

where

$\|A\|$ = the 7 x 3 matrix consisting of the Legendre Polynomials, P_o, P_2, and P_4, evaluated at the seven angles (Figure 5A).

$\|A^T\|$ = the transposed A matrix

$\|\omega\|$ = a diagonal matrix with elements consisting of the inverse squares of the standard deviations of the experimental $\bar{W}'(\theta_m)$ (Figure 5B)

$\|\mu\|$ = a one column matrix whose elements are the experimental values of $\bar{W}'(\theta_m)$ (Figure 5C)

$\|A'\|$ = the one column matrix whose elements are respectively the least-square coefficients A'_o, A'_2 and A'_4 (Figure 5D)

$\|A^T\omega A\|^{-1}$ = the inverse of the matrix obtained by multiplying the three designated matrices together. The diagonal terms of this matrix are the squares of the standard deviations of the least-square coefficients, A'_n.

The experimental values for the coefficients A'_n and their standard deviations, normalized so that $A'_o = 1$, are listed in Table 3. The corresponding values from Verser's work are included for comparison.

TABLE 3

Least Square Coefficients

	Verser	This Work
A'_o	1.0000 ± 0.0034	1.0000 ± 0.0026
A'_2	0.0961 ± 0.0055	0.0971 ± 0.0057
A'_4	0.0339 ± 0.0071	0.0231 ± 0.0066

MATRIX CONFIGURATIONS

$$\left\| \begin{matrix} P_o(\cos 90^\circ) & P_2(\cos 90^\circ) & P_4(\cos 90^\circ) \\ P_o(\cos 105^\circ) & P_2(\cos 105^\circ) & P_4(\cos 105^\circ) \\ P_o(\cos 120^\circ) & P_2(\cos 120^\circ) & P_4(\cos 120^\circ) \\ P_o(\cos 135^\circ) & P_2(\cos 135^\circ) & P_4(\cos 135^\circ) \\ P_o(\cos 150^\circ) & P_2(\cos 150^\circ) & P_4(\cos 150^\circ) \\ P_o(\cos 165^\circ) & P_2(\cos 165^\circ) & P_4(\cos 165^\circ) \\ P_o(\cos 180^\circ) & P_2(\cos 180^\circ) & P_4(\cos 180^\circ) \end{matrix} \right\|$$

(A)

$$\left\| \begin{matrix} \sigma^{-2}(90^\circ) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sigma^{-2}(105^\circ) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma^{-2}(120^\circ) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma^{-2}(135^\circ) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma^{-2}(150^\circ) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma^{-2}(165^\circ) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma^{-2}(180^\circ) \end{matrix} \right\|$$

(B)

$$\left\| \begin{matrix} \bar{W}'(90^\circ) \\ \bar{W}'(105^\circ) \\ \bar{W}'(120^\circ) \\ \bar{W}'(135^\circ) \\ \bar{W}'(150^\circ) \\ \bar{W}'(165^\circ) \\ \bar{W}'(180^\circ) \end{matrix} \right\|$$

(C)

$$\left\| \begin{matrix} A_o \\ A_2 \\ A_4 \end{matrix} \right\|$$

(D)

FIGURE 5

A. Experimental Anisotropies

The anisotropy is defined:

$$\bar{R} = \frac{\bar{W}(180^\circ) - \bar{W}(90^\circ)}{\bar{W}(90^\circ)} \tag{22}$$

The anisotropy for the least-square curve was calculated from the experimental correlation function. Since the anisotropy can be determined with much greater precision than can the least-square coefficients themselves, it provides a more sensitive means for comparing the experimental and theoretical functions. The experimental anisotropy is

$$\bar{R} = 0.167 \pm 0.013$$

The standard deviation was calculated by the formula presented by Klema and McGowan (6). The computer program for the calculation of $\bar{R}$ and its standard deviation is outlined in Appendix I.

CHAPTER VI

RESULTS AND CONCLUSIONS

A. COMPARISON BETWEEN EXPERIMENT AND THEORY

The experimental and corrected theoretical functions for this experiment are:

Experimental:

$$\bar{W}'(\theta) = (1.0000 \pm 0.0026) + (0.0971 \pm 0.0057)\, P_2 + (0.0231 \pm 0.0066)\, P_4$$

Theoretical:

$$\bar{W}(\theta) = 1.0000 \pm 0.0996\, P_2 + 0.00838\, P_4$$

The experimental anisotropy was calculated to be $\bar{R} = 0.167 \pm 0.013$ and is compared with Verser's value of $\bar{R} = 0.171 \pm 0.027$ and with the theoretical anisotropy corrected for the solid angle, $\bar{R} = 0.161$.

Figure 6 shows the experimental results and their standard deviations for this work and that of Verser. Also shown are the least-square correlation curves for both sets of data and the corrected theoretical correlation curve. All the curves have been normalized to unity at $\theta = 90^\circ$.

B. DISCUSSION AND CONCLUSIONS

From Figure 6, it can be seen that the curve obtained in this work agrees with that obtained by Verser. Both of these curves show an apparently real dip in the region from 105° to 135°. It is only a remote possibility that this dip can be attributed to statistical fluctuations, and it is unlikely to be due to instrumental effects.

Two conjectures of possible mechanisms are:

(a) The source may have crystallized resulting in preferential alignment of the nuclei within the crystal due to internal electric fields.

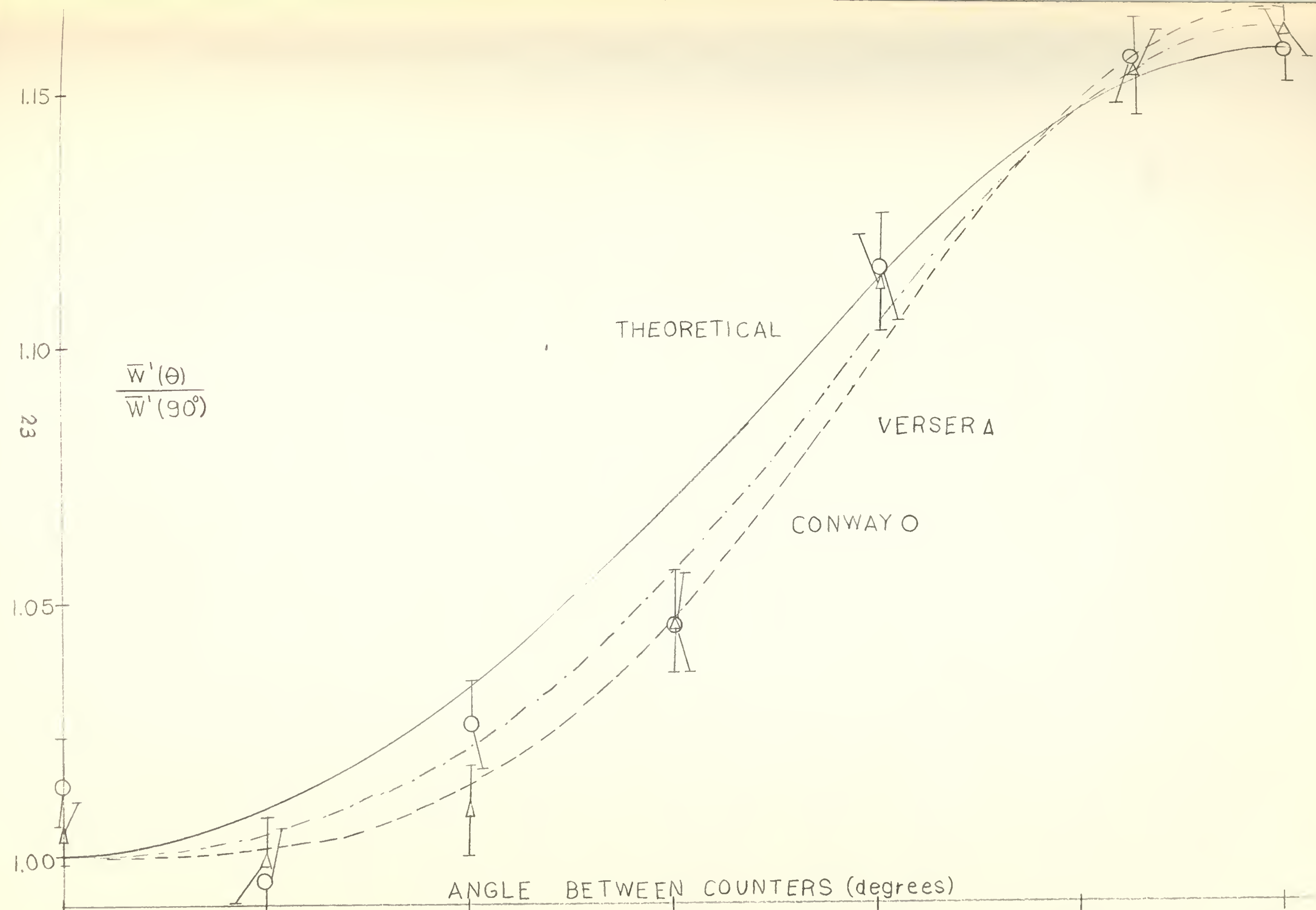

1.15
1.10
1.05
1.00
$\frac{\overline{W}'(\theta)}{\overline{W}'(90^\circ)}$
THEORETICAL
VERSER Δ
CONWAY O
ANGLE BETWEEN COUNTERS (degrees)
90
105
120
135
150
165
180

FIGURE 6

(b) The ferromagnetic properties of Cobalt could have led to a preferential alignment of the nuclei in the earth's magnetic field.

The following series of experiments are suggested for future work.

(a) The results for measurements conducted for angles between 180^{o} and 270^{o} should be compared with those already obtained.

(b) In order to check on the possible effects of orientation due to crystalline electric fields, the experiment should be repeated with the present source at various orientations relative to the fixed counter.

(c) In order to check on the possibility of orientation by magnetic effects the source should be placed in a magnetic field of known direction and the measurements repeated.

(d) A correlation curve using a powdered Cobalt-60 source in place of the present source should be obtained for comparison.

These experiments would determine conclusively if any effects causing preferential nuclear orientation are present.

The following instrumentation improvements are suggested in order to improve the stability of the equipment.

(a) A very stable power supply should be purchased to aid in preventing the line voltage fluctuations from interfering with the electronic system.

(b) The effect of temperature variations on the electronic system can be minimized by placing the equipment in a temperature controlled room for conducting future work.

(c) A slow coincidence unit whose resolving time is independent of the counting rate should be obtained.

The precision of the results should be improved by the addition of a fast coincidence channel working in conjunction with the slow coincidence unit to reduce the number of accidental coincidences.

Since the experimental curves using Cobalt-60 have not agreed with the theoretical curve, the experiments on Cobalt-60 should be continued until the source of the distrotion is ascertained. Perhaps the effect can be related to the physical properties of the $CoCl_2$ source.

APPENDIX I

Least-Square Fit of Experimental Results

The comparison of the experimental correlation function to the functional form of the theoretical correlation function given by Equation (1) is accomplished by the method of least-squares, as outlined by Rose (2). The analysis requires the solution of Equation (20) for the values of A'_n.

The computer solution of the matrix equation, like the solid angle calculation, is carried out in floating point format. In addition to the solution for the values of A'_n, the program also calculates the anisotropy by Equation (21), and its standard deviation by the formula presented by Klema and McGowan (6). A flow sheet outline of the program is given in Figure (7). In order to provide a certain amount of flexibility to the program, the angles used have been left as a parameter to be supplied. The program as written is, however, limited to seven different angular positions. The parameters needed for the program may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order:

B1 = weighted means of the correlation function in ascending angular order.

B2 = the standard deveations of the weighted means in the same order as above.

B3 = the values of the angles used in ascending order.

The program is available for future use on both bioctal tape in machine language, and IBM cards in assembly language. The bioctal tape contains the following:

1. The main program for calculation of A'_n
2. The program of normalization of the A'_n
3. The program for calculation of the resulting correlation function
4. The normalization of the correlation function
5. The calculation of the anisotropy

LEAST-SQUARE FIT FLOW CHART

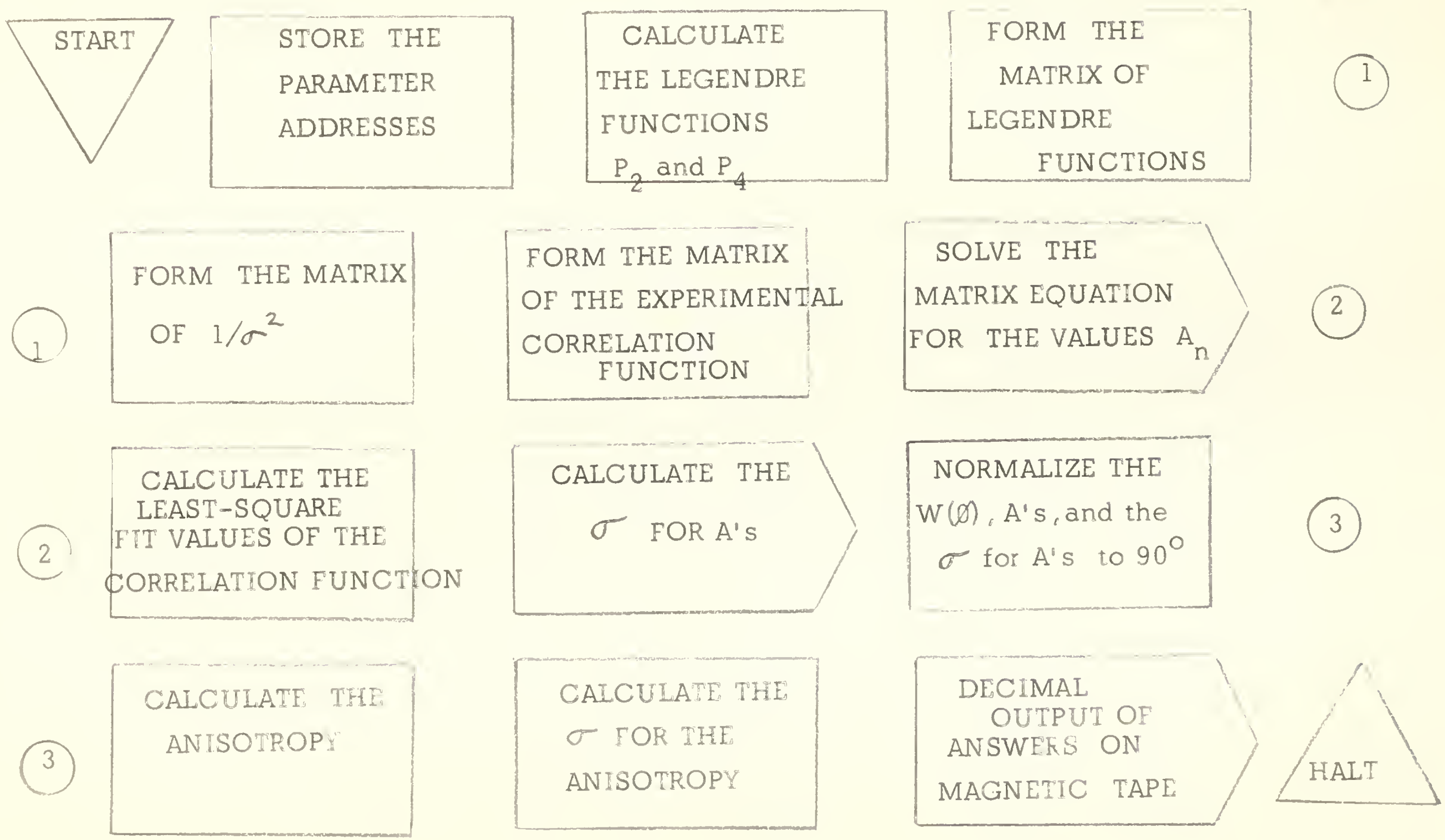


FIGURE 7

6. The calculation of the standard deviation for the anisotropy

7. The subroutines

   a. Floating Point Sine-Cosine

   b. Floating Point Square Root

   c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Lines 1 thru 3	The matrix inverse
Lines 4 thru 6	Check answer; included in the program is a check of the inverse which consists of multiplying the inverse by the original matrix
Line 7	The values of A'_o, A'_2 and A'_4
Line 8	The standard deviations of the A'_n
Line 9 thru 13	The resulting correlation functions
Line 14 and 15	The normalized correlation functions
Line 16	The normalized A'_n
Line 17	The normalized standard deviations of the A'_n
Line 18	The anisotropy
Line 19	The square of the standard deviation of the anisotropy

STATISTICAL ANALYSIS PROGRAM

```
            ORG     12000
            REM     BURTON J CONWAY APRIL 1961
            REM     LEAST SQUARE FIT OF ANGULAR
            REM     CORRELATION DATA.
            REM     MUST BE SUPPLIED WITH
            REM     PARAMETER ADDRESSES AS FOLLOWS.
            REM     B1  CORRELATION FUNCTION.
            REM     B2  SIGMA OF CORRELATION FUNCTION.
            REM     B3  ANGLES USED IN DEGREES.
    ZEUS    EQU     13000
    RHO     EQU     13100
    TRANS   EQU     13200
    ATW     EQU     13230
    ATWA    EQU     13260
    INVER   EQU     13500
    CHECK   EQU     13520
    IAT     EQU     13540
    IATW    EQU     13570
    ANS     EQU     13620
    FINIS   EQU     13630
    SINFL   EQU     60000
    MATRIX  EQU     10000
```

```
                         ANISO    EQU   13624
12000    56 1 12045               SIU   1 FORMMU
         50 1 00000               ENI   1 0
12001    57 2 12032               SIL   2 SIGMA
         56 2 12033               SIU   2 SIGMA+1
12002    50 2 00000               ENI   2 0
         50 0 00000               ENI   0 0
12003    56 3 12004               SIU   3 /+1
         50 3 00000               ENI   3 0
12004    12 1 00000      START    LDA   1 0
         32 0 12512               FMU   0 CONV
12005    75 4 60001               SLJ   4 SINFL+1
         50 0 00000               ENI   0 0
12006    50 0 00000               ENI   0 0
         50 0 00000               ENI   0 0
12007    50 0 00000               ENI   0 0
         50 0 00000               ENI   0 0
12010    20 1 12463               STA   1 TEMP
         50 0 00000               ENI   0 0
12011    54 1 00006               ISK   1 6
         75 0 12004               SLJ   0 START
12012    12 1 12463      NEXT     LDA   1 TEMP         STARTS FORMATION
         32 1 12463               FMU   1 TEMP         OF THE LEG. POL.
```

```
12013   20 0 12461          STA  0 DON
        32 0 12320          FMU  0 FLT2
12014   31 0 12316          FSB  0 FLT
        33 0 12317          FDV  0 FLT1
12015   20 1 12326          STA  1 WORK2
        12 0 12461          LDA  0 DON
12016   32 0 12322          FMU  0 FLT4
        20 0 12462          STA  0 DON+1
12017   12 0 12461          LDA  0 DON
        32 0 12461          FMU  0 DON
12020   32 0 12323          FMU  0 FLT5
        31 0 12462          FSB  0 DON+1
12021   30 0 12320          FAD  0 FLT2
        33 0 12321          FDV  0 FLT3
12022   20 1 12335          STA  1 WORK4
        50 0 00000          ENI  0 0
12023   54 1 00006          ISK  1 6
        75 0 12012          SLJ  0 NEXT
12024   12 0 12325   FORM   LDA  0 WORK1
        20 2 12434          STA  2 ABLE
12025   51 2 00001          INI  2 1
        12 1 12326          LDA  1 WORK2
12026   20 2 12434          STA  2 ABLE
        51 2 00001          INI  2 1
```

```
12027    12 1 12335             LDA  1 WORK4
         20 2 12434             STA  2 ABLE
12030    51 2 00001             INI  2 1
         50 0 00000             ENI  0 0
12031    54 1 00006             ISK  1 6
         75 0 12024             SLJ  0 FORM
12032    12 0 12316   SIGMA     LDA  0 FLT
         33 1 00000             FDV  1 0
12033    33 1 00000             FDV  1 0
         20 1 12463             STA  1 TEMP
12034    54 1 00006             ISK  1 6
         75 0 12032             SLJ  0 SIGMA
12035    50 2 00000             ENI  2 0
         50 1 00000             ENI  1 0
12036    12 1 12353   FORMCAD   LDA  1 CAD
         22 0 12043             AJP  0 /+5
12037    12 2 12463             LDA  2 TEMP
         20 1 12353             STA  1 CAD
12040    51 1 00001             INI  1 1
         50 0 00000             ENI  0 0
12041    54 2 00006             ISK  2 6
         75 0 12036             SLJ  0 FORMCAD
```

```
12042   75 0 12044            SLJ  0 /+2
        50 0 00000            ENI  0 0
12043   51 1 00001            INI  1 1
        75 0 12036            SLJ  0 FORMCAD
12044   50 1 00000            ENI  1 0
        50 2 00000            ENI  2 0
12045   12 1 00000   FORMMU   LDA  1 0
        20 1 12344            STA  1 MU
12046   54 1 00006            ISK  1 6
        75 0 12045            SLJ  0 FORMMU
12047   50 1 00000            ENI  1 0
        50 2 00000            ENI  2 0
12050   75 4 10000            SLJ  4 MATRIX          TRANSPOSE
        50 0 00000            ENI  0 0
12051   50 0 00000            ENI  0 0
        50 0 00000            ENI  0 0
12052   50 0 00000            ENI  0 0
        50 0 00002            ENI  0 2
12053   50 0 00007            ENI  0 7
        50 0 12434            ENI  0 ABLE
12054   50 0 00003            ENI  0 3
        50 0 06626            ENI  0 6626
12055   50 0 00000            ENI  0 0
        50 0 13200            ENI  0 TRANS
```

```
12056   75 4 10000      SLJ  4 MATRIX     ATW
        50 0 00000      ENI  0 0
12057   50 0 00000      ENI  0 0
        50 0 00000      ENI  0 0
12060   50 0 00000      ENI  0 0
        50 0 00004      ENI  0 4
12061   50 0 00003      ENI  0 3
        50 0 13200      ENI  0 TRANS
12062   50 0 00007      ENI  0 7
        50 0 12353      ENI  0 CAD
12063   50 0 00007      ENI  0 7
        50 0 13230      ENI  0 ATW
12064   75 4 10000      SLJ  4 MATRIX     ATWA
        50 0 00000      ENI  0 0
12065   50 0 00000      ENI  0 0
        50 0 00000      ENI  0 0
12066   50 0 00000      ENI  0 0
        50 0 00004      ENI  0 4
12067   50 0 00003      ENI  0 3
        50 0 13230      ENI  0 ATW
12070   50 0 00007      ENI  0 7
        50 0 12434      ENI  0 ABLE
```

```
12071    50 0 00003    ENI  0 3
         50 0 13260    ENI  0 ATWA
12072    75 4 10000    SLJ  4 MATRIX        INVERSE
         50 0 00000    ENI  0 0
12073    50 0 00000    ENI  0 0
         50 0 00000    ENI  0 0
12074    50 0 00000    ENI  0 0
         50 0 00005    ENI  0 5
12075    50 0 00003    ENI  0 3
         50 0 13260    ENI  0 ATWA
12076    50 0 00044    ENI  0 36D
         50 0 13272    ENI  0 ATWA+12
12077    50 0 00000    ENI  0 0
         50 0 13500    ENI  0 INVER
12100    75 4 10000    SLJ  4 MATRIX        CHECK
         50 0 00000    ENI  0 0
12101    50 0 00000    ENI  0 0
         50 0 00000    ENI  0 0
12102    50 0 00000    ENI  0 0
         50 0 00004    ENI  0 4
12103    50 0 00003    ENI  0 3
         50 0 13500    ENI  0 INVER
12104    50 0 00003    ENI  0 3
         50 0 13260    ENI  0 ATWA
```

```
12105   50 0 00003      ENI  0 3
        50 0 13520      ENI  0 CHECK
12106   75 4 10000      SLJ  4 MATRIX       IAT
        50 0 00000      ENI  0 0
12107   50 0 00000      ENI  0 0
        50 0 00000      ENI  0 0
12110   50 0 00000      ENI  0 0
        50 0 00004      ENI  0 4
12111   50 0 00003      ENI  0 3
        50 0 13500      ENI  0 INVER
12112   50 0 00003      ENI  0 3
        50 0 13200      ENI  0 TRANS
12113   50 0 00007      ENI  0 7
        50 0 13540      ENI  0 IAT
12114   75 4 10000      SLJ  4 MATRIX       IATW
        50 0 00000      ENI  0 0
12115   50 0 00000      ENI  0 0
        50 0 00000      ENI  0 0
12116   50 0 00000      ENI  0 0
        50 0 00004      ENI  0 4
12117   50 0 00003      ENI  0 3
        50 0 13540      ENI  0 IAT
```

```
12120    50 0 00007        ENI  0 7
         50 0 12353        ENI  0 CAD
12121    50 0 00007        ENI  0 7
         50 0 13570        ENI  0 IATW
12122    75 4 10000        SLJ  4 MATRIX        ANS
         50 0 00000        ENI  0 0
12123    50 0 00000        ENI  0 0
         50 0 00000        ENI  0 0
12124    50 0 00000        ENI  0 0
         50 0 00004        ENI  0 4
12125    50 0 00003        ENI  0 3
         50 0 13570        ENI  0 IATW
12126    50 0 00007        ENI  0 7
         50 0 12344        ENI  0 MU
12127    50 0 00001        ENI  0 1
         50 0 13620        ENI  0 ANS
12130    50 4 00000        ENI  4 0
         50 5 00000        ENI  5 0
12131    50 6 00000        ENI  6 0
         50 1 00000        ENI  1 0
12132    50 2 00000        ENI  2 0
         50 3 00000        ENI  3 0
12133    54 1 77777        ISK  1 77777
         75 0 12133        SLJ  0 /
```

12134	50 0 00000	ENI	0 0
	74 7 42040	EXF	7 42040
12135	75 4 71000	SLJ	4 71000
	50 0 00000	ENI	0 0
12136	01 0 13500	01	0 INVER
	04 0 00001	04	0 1
12137	12 0 12315	LDA	0 MIKE
	70 0 12136	RAD	0 /-1
12140	54 4 00002	ISK	4 2
	75 0 12135	SLJ	0 /-3
12141	54 1 77777	ISK	1 77777
	75 0 12141	SLJ	0 /
12142	54 1 77777	ISK	1 77777
	75 0 12142	SLJ	0 /
12143	50 0 00000	ENI	0 0
	74 7 42040	EXF	7 42040
12144	75 4 71000	SLJ	4 71000
	50 0 00000	ENI	0 0
12145	01 0 13520	01	0 CHECK
	04 0 00004	04	0 4
12146	12 0 12315	LDA	0 MIKE
	70 0 12145	RAD	0 /-1

```
12147     54 4 00002              ISK  4 2
          75 0 12144              SLJ  0 /-3
12150     54 1 77777              ISK  1 77777
          75 0 12150              SLJ  0 /
12151     50 0 00000              ENI  0 0
          74 7 42040              EXF  7 42040
12152     75 4 71000              SLJ  4 71000
          50 0 00000              ENI  0 0
12153     01 0 13620               01  0 ANS
          04 0 00007               04  0 7
                                  REM    STARTS FORMATION OF THE
                                  REM    CORRELATION FUNCTION
12154     12 0 13620   DUMP       LDA  0 ANS
          32 4 12434              FMU  4 ABLE
12155     20 0 13100              STA  0 RHO            AOPO IN STORAGE
          51 4 00001              INI  4 1
12156     12 0 13621              LDA  0 ANS+1
          32 4 12434              FMU  4 ABLE           A2P2 IN A REG
12157     30 0 13100              FAD  0 RHO            AOPO+A2P2 IN THE
          20 0 13100              STA  0 RHO            A REGISTER
12160     12 0 13622              LDA  0 ANS+2
          51 4 00001              INI  4 1
12161     32 4 12434              FMU  4 ABLE           A4P4 IN A REG
          30 0 13100              FAD  0 RHO            SUM IN A REG
```

```
12162   20 6 13000   STA 6 ZEUS     ANS TO STORAGE
        51 6 00003   INI 6 3
12163   54 4 00024   ISK 4 24
        75 0 12154   SLJ 0 DUMP
12164   12 2 13500   LDA 2 INVER
        75 4 12527   SLJ 4 SQRFL
12165   50 0 00000   ENI 0 0
        50 0 00000   ENI 0 0
12166   20 1 12501   STA 1 TTA
        51 2 00004   INI 2 4
12167   54 1 00002   ISK 1 2
        75 0 12164   SLJ 0 /-3
12170   50 1 00000   ENI 1 0
        50 2 00000   ENI 2 0
12171   50 3 00000   ENI 3 0
        50 4 00000   ENI 4 0
12172   54 1 77777   ISK 1 77777
        75 0 12172   SLJ 0 /
12173   50 0 00000   ENI 0 0
        74 7 42040   EXF 7 42040
12174   75 4 71000   SLJ 4 71000
        50 0 00000   ENI 0 0
```

```
12175   01 0 12501     01  0 TTA
        04 0 00010     04  0 10
12176   54 1 77777     ISK 1 77777
        75 0 12176     SLJ 0 /
12177   50 0 00000     ENI 0 0
        74 7 42040     EXF 7 42040
12200   75 4 71000     SLJ 4 71000
        50 0 00000     ENI 0 0
12201   01 0 13000     01  0 ZEUS
        04 0 00011     04  0 11
12202   12 0 12315     LDA 0 MIKE
        70 0 12201     RAD 0 /-1
12203   54 5 00004     ISK 5 4
        75 0 12200     SLJ 0 /-3
12204   12 1 13000     LDA 1 ZEUS        NORMALIZES THE
        33 0 13000     FDV 0 ZEUS        CORRELATION
12205   20 2 12472     STA 2 NORM        FUNCTION
        51 1 00003     INI 1 3
12206   54 2 00006     ISK 2 6
        75 0 12204     SLJ 0 /-2
12207   54 1 77777     ISK 1 77777
        75 0 12207     SLJ 0 /
12210   50 0 00000     ENI 0 0
        74 7 42040     EXF 7 42040
```

```
12211   75 4 71000      SLJ  4 71000       DUMPS THE
        50 0 00000      ENI  0 0           NORMALIZED
12212   01 0 12472       01  0 NORM        CORRELATION
        04 0 00016       04  0 16          FUNCTION
12213   12 0 12315      LDA  0 MIKE
        70 0 12212      RAD  0 /-1
12214   54 2 00001      ISK  2 1
        75 0 12211      SLJ  0 /-3
12215   50 1 00000      ENI  1 0
        50 0 00000      ENI  0 0
12216   12 1 13620      LDA  1 ANS
        33 0 13620      FDV  0 ANS
12217   20 1 12507      STA  1 AN
        50 0 00000      ENI  0 0
12220   54 1 00002      ISK  1 2
        75 0 12216      SLJ  0 /-2
12221   54 1 77777      ISK  1 77777
        75 0 12221      SLJ  0 /
12222   50 0 00000      ENI  0 0
        74 7 42040      EXF  7 42040
12223   75 4 71000      SLJ  4 71000
        50 0 00000      ENI  0 0
```

```
12224   01 0 12507      01  0 AN
        04 0 00020      04  0 20
12225   12 1 12501      LDA 1 TTA          NORMALIZES THE
        33 0 13000      FDV 0 ZEUS         SIGMAS FOR A
12226   20 1 12504      STA 1 TTAN
        50 0 00000      ENI 0 0
12227   54 1 00002      ISK 1 2
        75 0 12225      SLJ 0 /-2
12230   54 1 77777      ISK 1 77777
        75 0 12230      SLJ 0 /
12231   50 0 00000      ENI 0 0
        74 7 42040      EXF 7 42040
12232   75 4 71000      SLJ 4 71000
        50 0 00000      ENI 0 0
12233   01 0 12504      01  0 TTAN
        04 0 00021      04  0 21
12234   12 0 13022      LDA 0 ZEUS+22
        31 0 13000      FSB 0 ZEUS
12235   33 0 13000      FDV 0 ZEUS
        20 0 13624      STA 0 ANISO
12236   54 1 77777      ISK 1 77777
        75 0 12236      SLJ 0 /
12237   50 0 00000      ENI 0 0
        74 7 42040      EXF 7 42040
```

```
12240   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12241   01 0 13624           01  0 ANISO
        04 0 00022           04  0 22
12242   12 0 12314          LDA  0 ZRO
        20 0 12514          STA  0 ROB
12243   12 1 12344   AVG    LDA  1 MU
        31 2 13000          FSB  2 ZEUS
12244   20 0 12513          STA  0 EBSIL
        32 0 12513          FMU  0 EBSIL
12245   32 3 12353          FMU  3 CAD
        30 0 12514          FAD  0 ROB
12246   20 0 12514          STA  0 ROB
        51 2 00003          INI  2 3
12247   51 3 00010          INI  3 10
        50 0 00000          ENI  0 0
12250   54 1 00006          ISK  1 6
        75 0 12243          SLJ  0 AVG
12251   12 0 12514          LDA  0 ROB
        33 0 12324          FDV  0 FLT6
12252   20 0 12514          STA  0 ROB
        50 2 00000          ENI  2 0
```

```
12253   50 3 00000    ENI  3 0
        50 1 00000    ENI  1 0
12254   12 0 12514    LDA  0 ROB
        32 1 13500    FMU  1 INVER
12255   20 2 12515    STA  2 AXE
        51 1 00004    INI  1 4
12256   54 2 00002    ISK  2 2
        75 0 12254    SLJ  0 /-2
12257   12 0 12514    LDA  0 ROB
        32 0 13501    FMU  0 INVER+1
12260   20 0 12520    STA  0 COV02
        12 0 12514    LDA  0 ROB
12261   32 0 13505    FMU  0 INVER+5
        20 0 12521    STA  0 COV24
12262   12 0 13621    LDA  0 ANS+1
        30 0 13622    FAD  0 ANS+2
12263   20 0 12522    STA  0 A24
        32 0 12522    FMU  0 A24
12264   20 0 12523    STA  0 A242
        12 0 12522    LDA  0 A24
12265   33 0 13620    FDV  0 ANS
        20 0 12524    STA  0 GET
12266   32 0 12524    FMU  0 GET
        20 0 12524    STA  0 GET
```

```
12267   12 0 12522          LDA  0 A24
        32 0 13620          FMU  0 ANS
12270   20 0 12522          STA  0 A24
        50 0 00000          ENI  0 0
12271   12 0 12521          LDA  0 COV24
        32 0 12317          FMU  0 FLT1
12272   30 0 12516          FAD  0 AXE+1
        30 0 12517          FAD  0 AXE+2
12273   33 0 12523          FDV  0 A242
        20 0 12525          STA  0 WIT
12274   12 0 12515          LDA  0 AXE
        33 0 13620          FDV  0 ANS
12275   33 0 13620          FDV  0 ANS
        30 0 12525          FAD  0 WIT
12276   20 0 12525          STA  0 WIT
        12 0 12520          LDA  0 COV02
12277   30 0 12521          FAD  0 COV24
        33 0 12522          FDV  0 A24
12300   32 0 12317          FMU  0 FLT1
        20 0 12526          STA  0 WIT+1
12301   12 0 12525          LDA  0 WIT
        31 0 12526          FSB  0 WIT+1
```

```
12302   32 0 12524          FMU  0 GET
        20 0 13630          STA  0 FINIS
12303   54 1 77777          ISK  1 77777
        75 0 12303          SLJ  0 /
12304   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12305   75 4 71000          SLJ  4 71000
        50 0 00000          ENI  0 0
12306   01 0 13630           01  0 FINIS
        04 0 00025           04  0 25
12307   54 1 77777          ISK  1 77777
        75 0 12307          SLJ  0 /
12310   54 1 77777          ISK  1 77777
        75 0 12310          SLJ  0 /
12311   50 0 00000          ENI  0 0
        74 7 42040          EXF  7 42040
12312   74 0 42003          EXF  0 42003
        50 0 00000          ENI  0 0
12313   76 0 12000          SLS  0 12000
        50 0 00000          ENI  0 0
12314   00 0 00000   ZRO    CCT    0
        00 0 00000
12315   00 0 00004   MIKE     0  0 4
        00 0 00001            0  0 1
```

```
12316     20 0 14000   FLT      DEC   1.0
          00 0 00000
12317     20 0 24000   FLT1     DEC   2.0
          00 0 00000
12320     20 0 26000   FLT2     DEC   3.0
          00 0 00000
12321     20 0 44000   FLT3     DEC   8.0
          00 0 00000
12322     20 0 57400   FLT4     DEC   30.0
          00 0 00000
12323     20 0 64300   FLT5     DEC   35.0
          00 0 00000
12324     20 0 34000   FLT6     DEC   4.0
          00 0 00000
12325     20 0 14000   WORK1    DEC   1.0
          00 0 00000
12326     00 0 00000   WORK2    BSS   7
          00 0 00000
12335     00 0 00000   WORK4    BSS   7
          00 0 00000
12344     17 5 34167   MU       DEC   .5046D-6
          17 3 10477
```

```
12345    17 5 34103          DEC    .4925D-6
         21 2 75007
12346    17 5 34222          DEC    .5109D-6
         23 0 76631
12347    17 5 34276          DEC    .5211D-6
         06 7 01135
12350    17 5 34522          DEC    .5556D-6
         22 1 24417
12351    17 5 34601          DEC    .5667D-6
         75 2 36515
12352    17 5 34751          DEC    .5907D-6
         02 3 02276
12353    20 7 07231   CAD    DEC    .6574621D+17
         17 2 43106
12354    00 0 00000          OCT    0
         00 0 00000
12355    00 0 00000          OCT    0
         00 0 00000
12356    00 0 00000          OCT    0
         00 0 00000
12357    00 0 00000          OCT    0
         00 0 00000
12360    00 0 00000          OCT    0
         00 0 00000
```

12361	00 0 00000	OCT	0
	00 0 00000		
12362	00 0 00000	OCT	0
	00 0 00000		
12363	20 7 05367	DEC	.4938271D+17
	05 2 01171		
12364	00 0 00000	OCT	0
	00 0 00000		
12365	00 0 00000	OCT	0
	00 0 00000		
12366	00 0 00000	OCT	0
	00 0 00000		
12367	00 0 00000	OCT	0
	00 0 00000		
12370	00 0 00000	OCT	0
	00 0 00000		
12371	00 0 00000	OCT	0
	00 0 00000		
12372	00 0 00000	OCT	0
	00 0 00000		
12373	20 7 05015	DEC	.4526935D+17
	20 7 37137		

12374	00 0 00000	OCT	0
	00 0 00000		
12375	00 0 00000	OCT	0
	00 0 00000		
12376	00 0 00000	OCT	0
	00 0 00000		
12377	00 0 00000	OCT	0
	00 0 00000		
12400	00 0 00000	OCT	0
	00 0 00000		
12401	00 0 00000	OCT	0
	00 0 00000		
12402	00 0 00000	OCT	0
	00 0 00000		
12403	20 7 05176	DEC	.4725897D+17
	27 1 03164		
12404	00 0 00000	OCT	0
	00 0 00000		
12405	00 0 00000	OCT	0
	00 0 00000		
12406	00 0 00000	OCT	0
	00 0 00000		
12407	00 0 00000	OCT	0
	00 0 00000		

12410	00 0 00000	OCT	0
	00 0 00000		
12411	00 0 00000	OCT	0
	00 0 00000		
12412	00 0 00000	OCT	0
	00 0 00000		
12413	20 7 04477	DEC	.4164931D+17
	37 2 35173		
12414	00 0 00000	OCT	0
	00 0 00000		
12415	00 0 00000	OCT	0
	00 0 00000		
12416	00 0 00000	OCT	0
	00 0 00000		
12417	00 0 00000	OCT	0
	00 0 00000		
12420	00 0 00000	OCT	0
	00 0 00000		
12421	00 0 00000	OCT	0
	00 0 00000		
12422	00 0 00000	OCT	0
	00 0 00000		

```
12423   20 7 15041           DEC   .9124087D+17
        16 1 31752
12424   00 0 00000           OCT   0
        00 0 00000
12425   00 0 00000           OCT   0
        00 0 00000
12426   00 0 00000           OCT   0
        00 0 00000
12427   00 0 00000           OCT   0
        00 0 00000
12430   00 0 00000           OCT   0
        00 0 00000
12431   00 0 00000           OCT   0
        00 0 00000
12432   00 0 00000           OCT   0
        00 0 00000
12433   20 7 05367           DEC   .4938271D+17
        05 2 01171
12434   20 0 14000   ABLE    DEC   1.0
        00 0 00000
12435   57 7 73777           DEC   -.5
        77 7 77777
12436   17 7 66000           DEC   .375
        00 0 00000
```

12437	20 0 14000	DEC	1.0
	00 0 00000		
12440	60 0 11466	DEC	-.3995454
	73 1 10267		
12441	17 7 54455	DEC	.1434268
	71 7 14727		
12442	20 0 14000	DEC	1.0
	00 0 00000		
12443	60 0 23777	DEC	-.125
	77 7 77777		
12444	60 0 13277	DEC	-.289065
	76 5 40722		
12445	20 0 14000	DEC	1.0
	00 0 00000		
12446	17 7 64000	DEC	.250017
	10 7 23316		
12447	60 0 11400	DEC	-.40624
	05 1 74265		
12450	20 0 14000	DEC	1.
	00 0 00000		
12451	20 0 05000	DEC	.625
	00 0 00000		

```
12452     17 7 26004            DEC    .023471
          31 0 11317
12453     20 0 14000            DEC    1.0
          00 0 00000
12454     20 0 07144            DEC    .8995
          26 4 16254
12455     20 0 05364            DEC    .684614
          13 3 47506
12456     20 0 14000            DEC    1.0
          00 0 00000
12457     20 0 14000            DEC    1.0
          00 0 00000
12460     20 0 14000            DEC    1.0
          00 0 00000
12461     00 0 00000   DON      BSS    2
          00 0 00000
12463     00 0 00000   TEMP     BSS    7
          00 0 00000
12472     00 0 00000   NORM     BSS    7
          00 0 00000
12501     00 0 00000   TTA      BSS    3
          00 0 00000
12504     00 0 00000   TTAN     BSS    3
          00 0 00000
```

```
12507     00 0 00000   AN      BSS   3
          00 0 00000
12512     17 7 24357   CONV    DEC   .01745329252
          50 6 50451
12513     00 0 00000   EBSIL   BSS   1
          00 0 00000
12514     00 0 00000   ROB     BSS   1
          00 0 00000
12515     00 0 00000   AXE     BSS   3
          00 0 00000
12520     00 0 00000   COV02   BSS   1
          00 0 00000
12521     00 0 00000   COV24   BSS   1
          00 0 00000
12522     00 0 00000   A24     BSS   1
          00 0 00000
12523     00 0 00000   A242    BSS   1
          00 0 00000
12524     00 0 00000   GET     BSS   1
          00 0 00000
12525     00 0 00000   WIT     BSS   2
          00 0 00000
```

```
                                     REM    FLOATING POINT SQUARE ROOT
12527     75 0 00000    SQRFL        SLJ  0 0                ALARM EXIT
          56 1 12552                 SIU  1 SQFEXIT          STORE B1
12530     22 0 12550                 AJP  0 SQFEXIT-2      TEST 0 ARGUMENT
          22 3 12527                 AJP  3 SQRFL            TEST - ARGUMENT
12531     50 0 00000                 ENI  0 0
          42 0 12556                 SCM  0 SQMASK1          SET CORRECT
12532     05 0 00001                 ALS  0 1                SIGN FOR
          03 0 00045                 LRS  0 37D              EXPONENT
12533     22 3 12534                 AJP  3 /+1              COMPUTE
          11 0 00002                 INA  0 2                EXPONENT
12534     11 0 03777                 INA  0 3777             FOR ROOT
          03 0 00001                 LRS  0 1
12535     05 0 00044                 ALS  0 36D              SHIFT EXPONENT
          20 0 12561                 STA  0 SQERAS           AND SIGN
12536     44 0 12557                 LDL  0 SQMASK2
          01 0 00004                 ARS  0 4
12537     23 3 12540                 QJP  3 /+1
          01 0 00001                 ARS  0 1
12540     20 0 12562                 STA  0 SQERAS+1
          14 0 12555                 ADD  0 SQFCON3
12541     20 0 12563                 STA  0 SQERAS+2
          12 0 12554                 LDA  0 SQFCON2
```

```
12542   27 0 12563           DVF  0 SQERAS+2
        14 0 12553           ADD  0 SQFCON1
12543   50 1 00001           ENI  1 1
        04 0 00000           ENQ  0 0
12544   20 0 12563           STA  0 SQERAS+2
        12 0 12562           LDA  0 SQERAS+1
12545   27 0 12563           DVF  0 SQERAS+2
        14 0 12563           ADD  0 SQERAS+2
12546   01 0 00001           ARS  0 1
        55 1 12544           IJP  1 /-2
12547   01 0 00011           ARS  0 11
        42 0 12561           SCM  0 SQERAS
12550   32 0 12560           FMU  0 SQMASK3
        52 1 12527           LIU  1 SQRFL
12551   51 1 00001           INI  1 1
        57 1 12552           SIL  1 /+1
12552   50 1 00000  SQFEXIT  ENI  1 0
        75 0 00000           SLJ  0 0
12553   21 3 66405  SQFCON1  DEC     218518306D-8B45
        01 4 47436
12554   76 3 72106  SQFCON2  DEC     -302289917l4D-10B41
        43 6 47567
12555   03 0 56173  SQFCON3  DEC     154515776D-8B43
        52 7 71341
```

```
12556     20 0 00000   SQMASK1   OCT   2000000000000000
          00 0 00000
12557     37 7 77777   SQMASK2   OCT   3777777777774000
          77 7 74000
12560     20 0 14000   SQMASK3   OCT   2001400000000000
          00 0 00000
12561     00 0 00000   SQERAS    BSS   3
          00 0 00000
                                 END
```

APPENDIX II

Solid Angle Correction

The solid angle correction, which must be applied to the theoretical correlation function to enable a comparison to be made with the experimental correlation function, is described by Rose (1). The correction involves the numerical evaluation of the integrals given by Equation (14):

$$I_{ni} = \int_{o}^{\gamma} P_n(\text{Cos}\emptyset)\ (1-e^{-T_i X_i(\emptyset)})\ \text{Sin}\emptyset\ d\emptyset$$

and the subsequent solutions of Equations (15) and (16).

The computer solution for this correction was carried out in floating point format. The numerical integration was computed using an interval of 0.001 radians. A flow sheet outline of the program is given in Figure (8). The program must be supplied with the parameters Υ, h, r, and t same in both channels (see Table 4) thus enabling solid angle corrections to be made for any experimental set-up to which these corrections may be applicable. These parameters may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order

B1 = r (address of the crystal radius in centimeters)

B2 = t (address of the crystal thickness in centimeters)

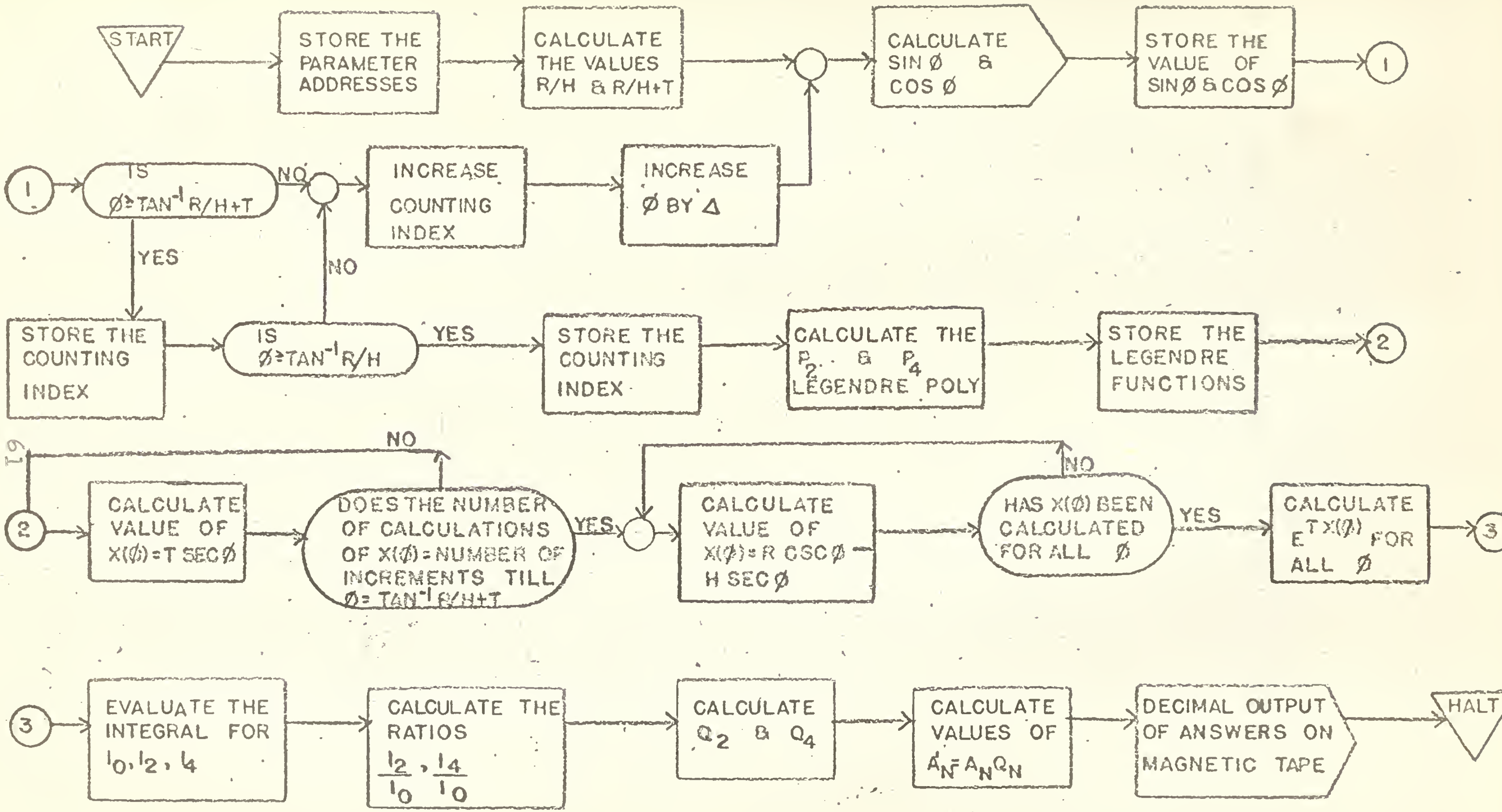
B3 = h (address of the crystal to source distance in centimeters)

B4 = Υ (the value of the full-energy absorption coefficient of the detector for the gamma ray in centimeters^{-1})

The values of the parameters used in the calculation of the corrected angular correlation coefficients for the theoretical correlation function and the results of the calculations are listed in Table 4.

The program is available for future use on bioctal tape in machine language and on IBM cards in assembly language. The bioctal tape contains all the necessary subroutines to enable a complete computation, i.e.

1. The main program for solution of Equation (14),
2. The subroutines



SOLID ANGLE CORRECTION FLOW CHART

a. Floating Point Sine-Cosine

b. Floating Point Exponential

c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Line 1	I_0
Line 2	I_2
Line 3	I_4
Line 4	I_2/I_0
Line 5	I_4/I_0
Line 6	Q_2
Line 7	A_2Q_2
Line 8	Q_4
Line 9	A_4Q_4

TABLE 4

SOLID ANGLE CORRECTION PARAMETERS

h (cm)	18.0
t (cm)	2.54
r (cm)	2.54
T (cm^{-1})	0.098
I_0	0.0079
I_2	0.0078
I_4	0.0076
$\frac{I_2}{I_0}$	0.9882
$\frac{I_4}{I_0}$	0.9609
Q_2	0.9765
Q_4	0.9234
Q_2A_2	0.0996
Q_4A_4	0.0084

SOLID ANGLE CORRECTION PROGRAM

```
        ORG     12000
        REM     BURTON J CONWAY APRIL 1961
        REM     SOLID ANGLE CORRECTIONS
        REM     OF THE THEORETICAL CORRELATION
        REM     CURVE.  MUST BE SUPPLIED
        REM     WITH PARAMETER ADDRESSES AS
        REM     FOLLOWS.
        REM     B1 ADDRESS OF XTAL RADIUS.
        REM     B2 ADDRESS OF XTAL THICKNESS.
        REM     B3 ADDRESS OF CRYSTAL TO
        REM     SOURCE DISTANCE.
        REM     B4 ADDRESS OF PARAMETER TAU.
HOLD    EQU     5500
TEMP    EQU     6500
WORK2   EQU     7500
WORK4   EQU     10500
HANS    EQU     11500
SOLD    EQU     12500
JAYO    EQU     13500
JAY2    EQU     13504
JAY4    EQU     13510
JAY20   EQU     13514
```

```
                         JAY40     EQU     13520
                         EXPFL     EQU     60600
                         SINFL     EQU     60000
12000     12 1 00000               LDA  1 0
          20 0 12163               STA  0 RAD
12001     12 2 00000               LDA  2 0
          20 0 12164               STA  0 THK
12002     12 3 00000               LDA  3 0
          20 0 12165               STA  0 HGT
12003     12 4 00000               LDA  4 0
          20 0 12166               STA  0 TAU
12004     12 0 12171               LDA  0 ZRO
          20 5 13500               STA  5 JAYO
12005     54 5 00030               ISK  5 30
          75 0 12004               SLJ  0 /-1
12006     12 0 12171               LDA  0 ZRO
          20 0 12151               STA  0 DELTA
12007     50 1 00000               ENI  1 0
          50 2 00000               ENI  2 0
12010     50 3 00000               ENI  3 0
          50 4 00000               ENI  4 C
12011     50 5 00000               ENI  5 0
          50 6 00000               ENI  6 0
```

```
12012     12 0 12163   START   LDA  0 RAD        FORMATION OF R/H
          33 0 12165           FDV  0 HGT
12013     20 0 12172           STA  0 PLEAS
          50 0 00000           ENI  0 0
12014     12 0 12165           LDA  0 HGT        FORMATION OF R/H+T
          30 0 12164           FAD  0 THK
12015     20 0 12175           STA  0 ONCE
          12 0 12163           LDA  0 RAD
12016     33 0 12175           FDV  0 ONCE
          20 0 12175           STA  0 ONCE
12017     12 0 12151   BGN     LDA  0 DELTA      SINE AND COSINE
          50 0 00000           ENI  0 0          FORMATION
12020     75 4 60001           SLJ  4 SINFL+1    COSINE
          50 0 00000           ENI  0 0
12021     50 0 00000           ENI  0 0
          50 0 00000           ENI  0 0
12022     50 0 00000           ENI  0 0
          50 0 00000           ENI  0 0
12023     20 1 06500           STA  1 TEMP       COSINE TO [illegible]
          12 0 12151           LDA  0 DELTA
12024     75 4 60000           SLJ  4 SINFL      SINE [illegible]
          50 0 00000           ENI  0 0
12025     50 0 00000           ENI  0 0
          50 0 00000           ENI  0 0
```

```
12026   50 0 00000          ENI  0 0
        50 0 00000          ENI  0 0
12027   20 1 05500          STA  1 HOLD        SINE TO STORAGE
        33 1 06500          FDV  1 TEMP        SINE/COSINE
12030   31 0 12175   REPL   FSB  0 ONCE        SINE/COSINE-R/H+T
        22 0 12141          AJP  0 FIRST       JUMPS IF A IS 0
12031   22 2 12141          AJP  2 FIRST       JUMPS IF A IS +
        51 1 00001          INI  1 1
12032   12 0 12152          LDA  0 DELTA+1
        30 0 12151          FAD  0 DELTA
12033   20 0 12151          STA  0 DELTA
        75 0 12017          SLJ  0 BGN
12034   56 1 12105   NEXT   SIU  1 JAY+3       STARTS FORMATION OF
        56 1 12073          SIU  1 INCL+5      THE LEGENDRE POL.
12035   56 1 12111          SIU  1 JAYTO+3
        56 1 12051          SIU  1 RMK
12036   56 1 12074          SIU  1 INCL+6
        56 1 12101          SIU  1 JAY-1
12037   56 1 12115          SIU  1 JAYFR+3
        50 1 00000          ENI  1 0
12040   12 1 06500          LDA  1 TEMP        COSB IN A REG.
        32 1 06500          FMU  1 TEMP
```

```
12041   20 0 12173          STA  0 DON
        32 0 12157          FMU  0 FLT2
12042   31 0 12155          FSB  0 FLT
        33 0 12156          FDV  0 FLT1        P2 IN A REG.
12043   20 1 07500          STA  1 WORK2
        12 0 12173          LDA  0 DON
12044   32 0 12161          FMU  0 FLT4
        20 0 12174          STA  0 DON+1
12045   12 0 12173          LDA  0 DON
        32 0 12173          FMU  0 DON
12046   32 0 12162          FMU  0 FLT5
        31 0 12174          FSB  0 DON+1
12047   30 0 12157          FAD  0 FLT2        P4 IN THE A REG.
        33 0 12160          FDV  0 FLT3
12050   20 1 10500          STA  1 WORK4
        50 0 00000          ENI  0 0
12051   54 1 00000   RMK    ISK  1 0           NUMBER OF ANGLES
        75 0 12040          SLJ  0 NEXT+4      INSERTED BY PROGRAM
12052   12 0 12164   HALF   LDA  0 THK         FORMATION OF XB
        33 1 06500          FDV  1 TEMP
12053   20 1 11500          STA  1 HANS
        50 0 00000          ENI  0 0
12054   54 1 00000          ISK  1 0           NUMBER INSERTED
        75 0 12052          SLJ  0 HALF        BY PROGRAM
```

```
12055   12 1 11500           LDA  1 HANS
        32 0 12166           FMU  0 TAU
12056   20 1 11500           STA  1 HANS
        50 0 00000           ENI  0 0
12057   54 1 00000           ISK  1 0            NUMBER ENTERED
        75 0 12055           SLJ  0 /-2          BY PROGRAM
12060   12 1 11500   POWER   LDA  1 HANS         STARTS FORMATION
        75 4 60600           SLJ  4 EXPFL        OF E TO THE TAU X
12061   50 0 00000           ENI  0 0
        50 0 00000           ENI  0 0
12062   20 1 12500           STA  1 SOLD
        50 0 00000           ENI  0 0
12063   54 1 00000           ISK  1 0
        75 0 12060           SLJ  0 POWER
12064   54 2 00001           ISK  2 1
        75 0 12066           SLJ  0 /+2
12065   75 0 12076           SLJ  0 HANG
        50 0 00000           ENI  0 0
12066   50 1 00000   INCL    ENI  1 0
        51 1 00001           INI  1 1
12067   12 0 12165           LDA  0 HGT          STARTS CALCULATION
        33 1 06500           FDV  1 TEMP         R CSCB-SECB
```

```
12070   20 1 12500          STA  1 SOLD
        12 0 12163          LDA  0 RAD
12071   33 1 05500          FDV  1 HOLD
        31 1 12500          FSB  1 SOLD
12072   32 0 12166          FMU  0 TAU
        20 1 11500          STA  1 HANS
12073   54 1 00000          ISK  1 0
        75 0 12067          SLJ  0 /-4
12074   50 1 00000          ENI  1 0
        56 1 12063          SIU  1 POWER+3
12075   50 1 00000          ENI  1 0
        75 0 12060          SLJ  0 POWER
12076   12 0 12155   HANG   LDA  0 FLT
        33 1 12500          FDV  1 SOLD
12077   20 1 12500          STA  1 SOLD
        12 0 12155          LDA  0 FLT
12100   31 1 12500          FSB  1 SOLD
        20 1 12500          STA  1 SOLD
12101   54 1 00000          ISK  1 0
        75 0 12076          SLJ  0 HANG
12102   12 0 12153   JAY    LDA  0 WORK          STARTS CALCULATION
        32 1 12500          FMU  1 SOLD          OF THE INTERGAL
12103   32 1 05500          FMU  1 HOLD
        32 0 12152          FMU  0 DELTA+1
```

```
12104   30 0 13500           FAD  0 JAYO
        20 0 13500           STA  0 JAYO
12105   54 1 00000           ISK  1 0
        75 0 12102           SLJ  0 /-3
12106   12 1 07500   JAYTO   LDA  1 WORK2
        32 1 12500           FMU  1 SOLD
12107   32 1 05500           FMU  1 HOLD
        32 0 12152           FMU  0 DELTA+1
12110   30 0 13504           FAD  0 JAY2
        20 0 13504           STA  0 JAY2
12111   54 1 00000           ISK  1 0          NUMBER OF TIMES
        75 0 12106           SLJ  0 /-3        TILL R/H
12112   12 1 10500   JAYFR   LDA  1 WORK4
        32 1 12500           FMU  1 SOLD
12113   32 1 05500           FMU  1 HOLD
        32 0 12152           FMU  0 DELTA+1
12114   30 0 13510           FAD  0 JAY4
        20 0 13510           STA  0 JAY4
12115   54 1 00000           ISK  1 0          NUMBER OF TIMES
        75 0 12112           SLJ  0 /-3        TILL R/H
12116   12 0 13504           LDA  0 JAY2
        33 0 13500           FDV  0 JAYO
```

```
12117    20 0 13514        STA  0 JAY20
         12 0 13510        LDA  0 JAY4
12120    33 0 13500        FDV  0 JAY0
         20 0 13520        STA  0 JAY40
12121    12 0 13514        LDA  0 JAY20
         32 0 13514        FMU  0 JAY20
12122    20 0 13524        STA  0 JAY40+4
         32 0 12167        FMU  0 THEOR
12123    20 0 13530        STA  0 JAY40+10
         12 0 13520        LDA  0 JAY40
12124    32 0 13520        FMU  0 JAY40
         20 0 13534        STA  0 JAY40+14
12125    32 0 12170        FMU  0 THEOR+1
         20 0 13540        STA  0 JAY40+20
12126    54 1 77777        ISK  1 77777
         75 0 12126        SLJ  0 /
12127    50 0 00000        ENI  0 0
         74 7 42040        EXF  7 42040
12130    75 4 71000        SLJ  4 71000
         50 0 00000        ENI  0 0
12131    01 0 13500         01  0 JAY0
         04 0 00001         04  0 1
12132    12 0 12154        LDA  0 MIKE
         70 0 12131        RAD  0 /-1
```

```
12133   54 5 00010           ISK  5 10
        75 0 12130           SLJ  0 /-3
12134   54 1 77777           ISK  1 77777
        75 0 12134           SLJ  0 /
12135   54 2 77777           ISK  2 77777
        75 0 12135           SLJ  0 /
12136   50 0 00000           ENI  0 0
        74 7 42040           EXF  7 42040
12137   74 0 42003           EXF  0 42003
        50 0 00000           ENI  0 0
12140   76 0 05000           SLS  0 5000
        50 0 00000           ENI  0 0
12141   12 0 12147   FIRST   LDA  0 SEC         MODIFIES THE PROGRAM
        20 0 12030           STA  0 REPL        WHEN THE VALUE OF
12142   12 0 12150           LDA  0 SEC+1       B  CHANGES
        20 0 12031           STA  0 REPL+1
12143   56 1 12054           SIU  1 HALF+2
        56 1 12057           SIU  1 HALF+5
12144   56 1 12063           SIU  1 POWER+3
        56 1 12075           SIU  1 INCL+7
12145   56 1 12066           SIU  1 INCL
        51 1 00001           INI  1 1
```

```
12146    75 0 12017           SLJ  0 BGN
         50 0 00000           ENI  0 0
12147    31 0 12172  SEC      FSB  0 PLEAS       PARAMETER TO MODIFY
         22 0 12034           AJP  0 NEXT        PROGRAM FOR B
12150    22 2 12034           AJP  2 NEXT        GREATER THAN R/H+T
         51 1 00001           INI  1 1
12151    00 0 00000  DELTA    OCT    0
         00 0 00000
12152    17 6 64061           DEC    .001
         11 5 64570
12153    20 0 14000  WORK     DEC    1.0
         00 0 00000
12154    00 0 00004  MIKE       0  0 4
         00 0 00001             0  0 1
12155    20 0 14000  FLT      DEC    1.0
         00 0 00000
12156    20 0 24000  FLT1     DEC    2.0
         00 0 00000
12157    20 0 26000  FLT2     DEC    3.0
         00 0 00000
12160    20 0 44000  FLT3     DEC    8.0
         00 0 00000
12161    20 0 57400  FLT4     DEC    30.0
         00 0 00000
```

```
12162    20 0 64300   FLT5    DEC    35.0
         00 0 00000
12163    20 0 25050   RAD     DEC    2.54
         75 3 41217
12164    20 0 25050   THK     DEC    2.54
         75 3 41217
12165    20 0 54400   HGT     DEC    18.0
         00 0 00000
12166    17 7 46213   TAU     DEC    .098
         20 7 12601
12167    17 7 46416   THEOR   DEC    .1020
         25 4 02030
12170    17 7 14511           DEC    .00907
         51 2 62577
12171    00 0 00000   ZRO     OCT    0
         00 0 00000
12172    00 0 00000   PLEAS   BSS    1
         00 0 00000
12173    00 0 00000   DON     BSS    2
         00 0 00000
12175    00 0 00000   ONCE    BSS    1
         00 0 00000
                              END
```

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